adaptation to particular purposes, like high-speed tools or armour-plate. This has the incidental but far-reaching industrial consequence that workmen of great individual skill in these industries are much less necessary now than formerly. Everything is accomplished by bringing temperature conditions under mechanical control, and making them absolutely reproducible without the exercise of critical judgment on the part of anyone.

A more intimate knowledge of the behaviour of the minerals themselves finds almost immediate industrial application. An industry which has grown to enormous proportions in recent years is the manufacture of Portland cement, about which little more has been known than that if certain natural minerals were taken in the proper proportions and heated in a peculiar furnace developed by experience, the resulting product could be mixed with water to form an artificial stone which has found extensive application in the building trades. Chemical analysis readily established the fact that the chief ingredients in a successful Portland cement were lime, alumina, and silica, with a small admixture, perhaps, of iron and magnesia; but the relation in which these ingredients stood one to another—that is, which of them were necessary and which merely incidental—and in what compounds and what proportions the necessary ingredients required to be present, has never been satisfactorily established. When we know the stable compounds which lime, alumina, and silica can combine to form, together with the conditions of equilibrium between these for different temperatures and percentages of each component, a formula can be written offhand for a successful Portland cement from given ingredients somewhat as an experienced cook might write out the recipe for a successful dish. Such definite and valuable knowledge is not beyond our reach. To obtain it requires, in fact, precisely the same system of procedure as that described above, which has already been successfully applied to many of the natural minerals reproduced and studied in the Geophysical Laboratory during the past five years. It happens that we have examined a considerable number of these very mixtures in our recent work upon the rocks. All the compounds of lime, silica, and alumina have been established, and a portion of the silica-magnesia series and their relations have been definitely determined throughout the entire range of accessible temperatures. There is no reason to apprehend serious difficulty in applying the same procedure to the commercial ingredients of Portland cement, and replacing the present rule-of-thumb methods and uncertain products with dependable cements. The problem of determining the relation of the ingredients in commercial cement and the conditions necessary for its successful formation is exactly the same in character as that of determining the conditions of formation of the rocks of the earth.

A physico-chemical investigation of the sulphide ores over a wide range of temperatures and pressures has also been undertaken, which has developed a large body of exact information of value in the mining industry. And such illustrations could be continued almost indefinitely if it would serve any useful purpose to do so.

The industrial world is not, as a rule, interested in scientific principles; the principle must first be narrowed down to the scope of the industrial requirement before its usefulness is apparent. The immediate effect of an industrial point of view is therefore to restrict investigation at the risk of losing sight of underlying principles entirely. An illustration of this has come down to us through the pages of history of a character to command and receive the utmost respect, for such another can hardly be expected to occur. We have honoured the early philosophers for their splendid search after broad knowledge; but in what is now the field of chemistry, they allowed themselves to be turned aside to the pursuit of a single, strictly utilitarian problem —the transmutation of base metals into gold. The history of chemistry is a history of this one problem from the fourth to the sixteenth century—twelve centuries before a man arose whose broader point of view enabled him to divert the fruitless search into other channels, from which a science has slowly arisen which is now so broad as to overlap most of the other sciences, and withal so practical that scarcely an industry is entirely independent of it.

The so-called practical questions may therefore as well be left to take care of themselves. There has been no lack of ingenuity in making profitable application of systematic knowledge whenever the need for it became insistent, for the rewards of such effort are considerable. And it is no longer an argument against proceeding to establish relationships in a new field that the scope of their application cannot be completely foreseen.

Now, what more promising questions occur to one than these: If the earth was originally fluid, as it appears to have been, and has gradually cooled down to its present state, its component minerals must at some time have been much more thoroughly mixed than now; how did they come to separate in the process of cooling into highly individualised masses and groups as we now find them, and what were the steps in their deposition? If the whole earth was hot, whence came the marble of which we have so much and which can withstand no heat? What has given us the valuable deposits of iron, of gold, of precious stones? What determines the various crystal forms found in the different minerals, and what is their relation? Some must have formed under pressure, some without pressure, some with the help of water, and some without. Where is the centre, and what the source of energy in our volcanoes? All these questions, and many more, the geophysicist may attempt to answer.

THE AGE OF THE EARTH.[1]

THE doctrine of uniformity in geology stated by Hutton in the words "we find no vestige of a beginning and no prospect of an end" was accepted by many until Lord Kelvin surprised this school of geologists in 1868 by drawing a very decided limit to the possible age of the earth.

Lord Kelvin assumed that in the remote past the earth was molten, and that it cooled down as a whole uniformly until the crust just solidified. Then the earth's interior is at a definite temperature (which we can now roughly estimate from the melting point of the rocks of the crust), while the surface has much the same temperature as now. The rate of cooling is determined by the thermal conductivity of the crust, *i.e.* by the rate at which the interior heat can escape.

It becomes possible to calculate what the temperature gradient near the surface will be at any subsequent time, or conversely, if we know the temperature gradient, to calculate what time has elapsed since the crust solidified.

By the age or antiquity of the earth I understand Lord Kelvin means the time that has elapsed since the crust solidified. The "geological age" would be less than this. The antiquity of a rock (or mineral) would only in the case of the oldest rocks be the same as the geological age. Thus the age of a mineral is a minimum estimate of the earth's age.

The temperature gradient at a depth x and time t is

$$d\theta/dx = \theta_0 e^{-x^2/4Kt} / \sqrt{4\pi Kt}.$$

where θ_0 is the initial surface temperature, K the conductivity of the material of the earth.

In applying this to the earth, we notice that x is small and t large, so that

$$d\theta/dx = \theta_0 / \sqrt{4\pi Kt}.$$

All these quantities are known except t. Lord Kelvin's estimates of the antiquity of the earth, using this method, varied a good deal, but forty million years was the maximum he would admit latterly.

Sources of heat, the radio-active elements, are now known which Lord Kelvin did not, of course, take into account. The earth can no longer be regarded as a body possessing only its sensible heat to supply the stream continually flowing from the interior to the surface—heat which is, presumably, radiated into space.

Lord Kelvin's treatment of the problem might be modified by taking into account the additional supply of "radio-active" heat. But the discoveries of radio-activity afford, it appears to the writer, an alternative treatment of the history of the earth which is more convincing. This treatment consists in accepting the antiquity of the earth, as found by Prof. Strutt using a radio-active method, and then examining the heat of the earth in the light of that result. Every estimate as to the age of the earth assumes to some degree a uniformity of present phenomena throughout the whole life of the earth; this uniformity is assumed by Sir Archibald Geikie in the rate of deposition of sediments,[2] by Prof. Joly for the addition of sodium to the sea,[3] by Lord Kelvin for the conduction of heat by rocks, and, finally, by Prof. Strutt for the rate of accumulation of helium in minerals or rocks.[4] Now of all these processes the last is the only one which is not altered by temperature, pressure, or other physical conditions.

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[1] Portion of the presidential address delivered to Section A, Australasian Association for the Advancement of Science, 1911, by Prof. T. H. Laby.

Prof. Strutt has concluded from a very refined determination of (1) the present rate of production of helium, and (2) the total accumulated helium in thorianite that it has taken 280 million years for the helium to accumulate. As the earth is presumably older than the mineral, this is a minimum age for the earth.

The Heat of the Earth.

The question at once arises how is it that the temperature gradient of the crust is not less than it actually is, for, according to Lord Kelvin, after only forty million years the gradient would have fallen to the present value. During the remaining 240 million years it would have gone on decreasing at a rate proportional to the square root of the time. It becomes evident, then, that there is actually a need for the heat supplied by the radio-activity of the crust if all these deductions are to be reconciled.

The Heat Stream from the Interior.

The heat stream from the interior is that flowing through the earth's surface layers. This is

$$\begin{aligned} H &= 4\pi r^2 K\, d\theta/dr \\ &= 5{\cdot}1 \times 10^{18} \times 0{\cdot}004 \times 1/3200 \\ &= 6{\cdot}4 \times 10^{12} \text{ calories per sec.,} \end{aligned}$$

where r is the earth's radius, $d\theta/dr$ the temperature gradient of the crust at the earth's surface, and K its thermal conductivity. We must attempt to substitute such numerical values for the temperature gradient and the conductivity as will give a correct result for the earth's whole surface. The nature of the data is indicated by the following[5] estimates:—

Land Surface; Average Temperature Gradient			
Prestwich ...	1° C. per 2430 cm.	Geikie ...	1° C. per 3100 cm.
Kelvin	„ 2750 „	Brit. Assn. ...	„ 3240 „
Schardt ...	„ 3200 „	C. King ...	„ 3890 „

The value used above is 1° per 3200 cm.

Land Surface	Conductivity at ordinary temperature in calorie degree^{-1} cm.$^{-1}$ sec.$^{-1}$
Sedimentary rocks	0·0055 to 0·0021; mean 0·0041
Igneous rocks ...	0·0053 to 0·0017; mean 0·0042

There is more uncertainty in the value of K than in that of $d\theta/dr$. A more accurate estimate of the heat loss of the earth is desirable. Convection currents make the conduction method ordinarily inapplicable to the sea or lakes; but under special conditions, such as fresh water between 0° and 4° C., might not the method be applicable to a lake?

Heat from Radium and Thorium in Rocks.

Lord Kelvin supposed that this heat stream, which we see amounts to 6×10^{12} calories per sec., came from the sensible heat of the earth's interior as it cooled by loss to the surface. That the heat of disintegration of radium might play an important part in cosmical physics was pointed out by Rutherford and Soddy.[6] The accurate determination of radium and thorium in rocks has shown that there is an embarrassingly large supply of heat being continuously emitted by these substances. Determinations of radium in rocks have been made by Strutt and Joly and others, but there is need for a systematic survey.

Radium in Igneous Rocks.

Number of rocks	Mean radium content in gm. per gm. of rock	Observer
28	$1{\cdot}7 \times 10^{-12}$	Strutt (Proc. Roy. Soc., May, 1906) corrected by Eve.
4	2·16 „	Eve and McIntosh (Phil. Mag., Aug., 1907).
19	0·79 „	Fletcher (Phil. Mag., July, 1909, in Joly's laboratory).
13	1·46 „	Farr and Florance (Phil. Mag., Nov., 1909).
Mean 64	1·3 „	Observers other than Joly.
126	7·01 „	Joly ("Radioactivity and Geology," Phil. Mag., Oct., 1909).

There is rather a wide difference between the mean of Joly's large number of determinations and the mean of other observations. There is clearly a discrepancy, which would probably be most quickly elucidated by the chief observers determining the radium in specimens of the same rock. If we give equal weight to the mean of Joly's observations 7×10^{-12}, and to $1{\cdot}3 \times 10^{-12}$ the mean of other observers, the final average is $4{\cdot}1 \times 10^{-12}$ gm. Now the heat given out by radium[7] in complete radio-active equilibrium (uranium to radium F)[8] is 0·06 calorie per sec. per gm., so that each gm. of the earth's crust, on account of the radium it contains, is the source of $4{\cdot}1 \times 10^{-12} \times 0{\cdot}06 = 2{\cdot}5 \times 10^{-13}$ calorie per sec., a source of heat unaffected, so far as experiment has shown, by temperature or pressure.

Thorium in the Earth's Crust.

But the uranium-radium series are not the only source of such heat; thorium is also widely distributed. Fewer rocks have been examined for it than for radium, but the following results have been recorded:—

Thorium in Igneous Rocks.

Number of rocks	Locality	Thorium per gm. of rock	Observer
19	Transandine	$0{\cdot}56 \times 10^{-5}$	Fletcher, Phil. Mag., July, 1910
59	St. Gothard and Lavas	1·3 „	Joly, Phil. Mag., July, 1909
4	European ...	5·0 „	Blanc, Phil. Mag., 1909
Mean for 82		$1{\cdot}3 \times 10^{-5}$	

The heat emitted by thorium in radio-active equilibrium is 5×10^{-9} calories per sec. per gm.,[9] and that by the average amount of thorium in rocks $6{\cdot}5 \times 10^{-14}$ cal. sec.$^{-1}$ gm.$^{-1}$.

Heat due to Radium and Thorium in Rocks.

Thus the heat emitted by the uranium, radium, and thorium found in surface rocks is $(24{\cdot}6+6{\cdot}5)10^{-14} = 3 \times 10^{-13}$ cal. per sec. per gm. Blanc,[10] having found nearly four times as much thorium as our mean value, concluded that thorium contributed as much heat as uranium and radium.

Distribution of Radio-active Elements.

If the whole mass of the earth (6×10^{27} gm.) were the source of as much radio-active heat as the surface rocks, the heat emitted would be $1{\cdot}8 \times 10^{15}$ calories per sec., or about 300 times the heat flowing from the interior as deduced from the conductivity and temperature gradient of the surface rocks. But if the interior of the earth gains more heat than it loses, then its temperature is rising; nor is the geological and other evidence that the earth was once hotter than now the only contradiction to a "heating-up" earth.

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[2] Geikie, Brit. Ass. Rep., 1899.
[3] Joly, Brit. Ass. Rep.
[4] Strutt, Proc. Roy. Soc.
[5] Joly, "Radioactivity and Geology."
[6] Phil. Mag., May, 1903; Proc. Roy. Soc.
[7] Von Schweidler and Hess, "Le Radium," February, 1909.
[8] Boltwood, *Amer. Journ. Sci.*, 1908.
[9] Pegram and Webb, *Phy. Rev.*, 1908.
[10] Science Abs., No. 1057, 1909.

Assuming, as before, the antiquity of the earth to be at least 300 million years (t), then in that period a supply of heat of 3×10^{-13} cal. per gm. per sec. (h) would have raised the interior of the earth to a temperature given by

$$S\theta = ht$$
$$\theta = 3\times10^{-13}\times3\times10^{8}\times3{\cdot}2\times10^{7}/0{\cdot}02 = 14{,}000^{\circ}\text{ C.},$$

where S is the specific heat of the internal material. Though loss by conduction to the surface and latent heat effects are here neglected, the calculation is sufficient to show that a uniform distribution of the radio-active elements would give rise to internal temperatures too high to be reconciled with the observed temperature gradients.[11] We may safely conclude that there is very much less uranium, radium, and thorium in the inner portion of the earth than there is in the crust, and a maximum limit may be assigned to the content of radio-active elements. It would appear a minimum limit may also be set.

According to Lord Kelvin, as we have seen above, a period of cooling of more than forty million years could not have elapsed between the solidification of the terrestrial crust and the establishment of the present temperature gradient. If, however, the antiquity of the earth is more than 300 million years, then the temperature gradient has been maintained by some other source of heat, and the radio-activity of the rocks is amply sufficient for the purpose if it extends to quite moderate depths. The present temperature gradient would be maintained for an indefinite time if the stream of heat from the interior came from the radio-activity of the rocks.

There would need to be $6\times10^{12}/0{\cdot}06 = 10^{14}$ gm. of terrestrial radium to supply the heat lost by conduction, for a layer of the earth's crust 14 km. deep, if of density 3, has a mass of $2{\cdot}1\times10^{25}$, and it would give out $2{\cdot}1\times10^{25}\times3\times10^{-13} = 6\times10^{12}$ cal./sec., assuming the content in this surface layer of radium and thorium, and therefore the heat emission was that of the surface rocks. There is very probably at least this amount of the radio-active elements; otherwise it is not apparent why the temperature gradient of the crust has its present value, though the antiquity of the earth probably exceeds 300 million years. If the age greatly exceeds that period, then the present temperature gradient can depend but little on the secular cooling of the earth from a molten state.

Prof. Strutt[12] has determined the minimum age of thorianite by evaluating the ratio

$$\frac{\text{The quantity of helium in the mineral at present}}{\text{The rate at which the helium is produced}}.$$

The refinement of the experiment will be appreciated when it is recalled that the rate of production of the helium is only 4×10^{-8} c.c. per gm. of thorianite per year. He found, as already mentioned, 280 million years for the age of one specimen and 250 millions for another.

To deduce a minimum age for a mineral in this manner it must be assumed that—

(1) There was no original store of helium in the mineral when it was formed.

(2) The mineral has not gained helium at any time except as it does now.

(3) That the present rate of accumulation of helium is the same as in the remote past, when possibly high pressures and temperatures obtained.

The observational basis for these assumptions are:—

For (1) and (2). If the helium was originally present in the mineral when it was formed, or added later, then we would expect to find helium in other minerals in which helium is not now accumulating, but no such minerals are known. Helium is only found in appreciable quantities when associated with thorium and uranium. The mechanism[13] of how it is continuously and unchangingly produced from these elements is known in great detail.

For (3). That radio-active changes are independent of temperature and pressure has been repeatedly tested and confirmed.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

THE Marquise Arconati Visconti has made a donation of 500,000 francs to the University of Paris, to be employed for the benefit of the faculties of science and arts.

IN connection with the Institute of Chemistry, Mr. C. F. Cross will deliver the first of two lectures on "Cellulose" at University College, London, on Friday, January 26. Sir William Ramsay, K.C.B., F.R.S., will preside.

THE post-graduate scholarship, of the value of 200*l.* per annum, in naval architecture has been awarded by the Royal Commissioners for the Exhibition of 1851 to Mr. Arthur Cannon, of Glasgow University, and formerly of the Royal Naval College, Greenwich.

WE learn from the issue of *Science* for December 15, 1911, that nearly a hundred students from the college of engineering of the University of Wisconsin were then on their yearly tour of inspection of great engineering plants of the eastern States. Engineering plants in Chicago, Milwaukee, Niagara Falls, Pittsburg, Schenectady, N.Y., and New York City were visited. These tours are required of students of engineering during their junior and senior years, and are arranged to cover industries that illustrate the work of the course pursued by the student. Four professors accompanied the students on their tour of inspection.

THE annual meeting of the Geographical Association will be held on January 13 at University College, Gower Street, London, W.C. In the morning, at 11 a.m., a discussion on the organisation of home-work in school geography will be opened by Prof. L. W. Lyde, and a paper on the population of the world will be read by Prof. A. J. Herbertson. In the afternoon, at 3 p.m., Dr. G. R. Parkin will deliver his presidential address, and afterwards Prof. Herbertson will exhibit lantern views of typical land-forms selected by a committee of the International Geographical Congress, and Miss S. Nicholls maps and views of typical land-forms in the Near East.

IT is announced in *Science* that by the will of Mrs. Jan K. Sacher the University of California is to receive 100,000*l.* The will stipulates that 40,000*l.* is to be spent on a granite campanile tower, 300 feet in height, to be erected in the centre of the University grounds. An endowment of 100,000*l.* has been secured, we learn from the same source, by Huron College, in Huron, S.D. St. Lawrence University, too, has obtained a 40,000*l.* endowment fund, of which the General Education Board has contributed 10,000*l.* Our contemporary also states that by the will of Miss J. M. Smith the sum of 1000*l.* is given to the American Association for the Advancement of Science. Similar bequests are made to the National Geographic Society of Washington and to the American Forestry Association of Washington. Other items of interest to men of science are 2000*l.* to the University of Pittsburg, 2000*l.* to the Allegheny Observatory, and 1000*l.* to the School of Liberal Arts and Sciences.

THE Senate of the University of St. Andrews has decided to confer the honorary LL.D. degree, *in absentia*, upon the following distinguished men, who were chosen for the degree on the occasion of the celebration of the 500th anniversary of the foundation of the University last September, but were unable to be present on that occasion:—Prof. Pietro Blaserna, professor of experimental physics in the University of Rome, president R. Accademia dei Lincei; Prof. M. J. M. Hill, F.R.S., Astor professor of pure mathematics, University College, London, and lately Vice-Chancellor of the University of London; Prof. Hugo Kronecker, professor of physiology, University of Berne; Prof. G. M. Mittag-Leffler, professor of pure mathematics in the University of Stockholm and Rector of that University, founder and editor of *Acta Mathematica*; M. Paul Meyer, directeur de l'Ecole Nationale des Chartes, Paris, professeur honoraire au Collège de France; Prof. Karl Pearson, F.R.S., Galton professor of eugenics and director of the Laboratory of National Eugenics, University of London; Mr. Charles D. Walcott, secretary of the Smithsonian Institution, Washington, U.S.A.; and Prof. P. Zorn, professor of international law in the University of Bonn.

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[11] This will be seen at once to follow from a calculation given by Strutt, Proc. Roy. Soc., p. 482, 1906.

[12] Proc. Roy. Soc., lxxxiv., 379, 1910.

[13] See for example Rutherford, Nobel lecture, 1908.